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ADDRESS

Delivered by the President, Mr. E. B. Knobel, on presenting the Gold Medal to Professor H. C. Vogel.

The Council have awarded the Gold Medal to Dr. Hermann Carl Vogel for his "Spectroscopic and Other Astronomical Observations," and it is now my privilege to lay before you some of the considerations which have influenced them, in bestowing the highest honour in their power, upon the Director of the Astrophysical Observatory at Potsdam.

In reviewing the numerous observations and researches, conducted with such refinement and high intelligence as distinguishes Dr. Vogel's career as an astronomer, it is, perhaps, natural that our attention should first be given to those spectroscopic investigations by which he has more conspicuously enriched our science, and in which he has developed a precision that is both exceptional and remarkable.

It seems probable, that researches in stellar astronomy which depend upon the analysis of the light emitted by the stars, will afford us in some respects results available for more exact conclusions, than those made by the ordinary methods of observation and measurement. By the latter, we are able to determine the movements of stars transversely to the line of sight, but only in angular measures, which, save in a very few cases, cannot be translated into units of distance, and in those instances the probable errors are very large. But, incredible as it would seem, the spectroscope, wielded with such delicate and refined skill as characterises the researches we have to consider, teaches us the velocity at which stars are approaching or receding from the earth, with a probable error which may be even less than a mile per second of time.

Such precision as has been attained, reveals to us a means of partially unravelling some of the complexities of the stellar movements, and enables us to penetrate into some of the mysteries of the universe of stars, which a few years ago would have been considered altogether beyond the human intellect to unfold. Not only are we thus able to ascertain the general drift of stars and star-systems, but also to obtain an imperishable record of the internal motions within those systems.

The physical principle underlying such investigations, is of a sufficiently simple character; and was first suggested by Doppler

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in 1841, as an extension of the principle on which he had shown that a sound should become sharper or flatter, if there were an approach or a recession between the ear and the source of the sound. Doppler supposed that stars might in this way change their colour as observed by eye, but he did not know of the stores of invisible light beyond both limits of the visible spectrum, ready to be lowered or raised into visibility, so that, as a matter of fact, no such change of colour would occur.

In 1848, Fizeau investigated the theory of Doppler with regard to sound, and offered an experimental proof of its correctness; and, in applying it to light, he pointed out the importance of considering the individual wave-lengths, and mentioned that though the enormous velocity of light presented a great difficulty in any experimental demonstration, he nevertheless expressed a confident belief that such proof would eventually be forthcoming. But it was not until spectrum analysis had enabled us to detect the lines of terrestrial substances in the stars, that this principle, in the hands of Huggins, became, in 1868, of practical importance in astronomy.

Eight years ago the high value of physical researches on the motion of stars in the line of sight, was acknowledged by the Council, in awarding the Gold Medal to him, to whom the honour justly belongs of originating this branch of observational astronomy—our Foreign Secretary, Dr. Huggins.

In the address delivered on that occasion by the President, Mr. Dunkin, the history of Dr. Huggins's important researches was clearly set forth, and it will be remembered that his observations were first published in the *Philosophical Transactions* for 1868.

About this time, Dr. Vogel commenced astrophysical investigations at the University Observatory of Leipzig, his interest in this study having been excited by his acquaintance with Zöllner; and in 1869, not long after the important discovery of Lockyer and Janssen, he assisted Zöllner in his spectroscopic observations of the solar prominences. But on his appointment to Von Bülow's private observatory at Bothkamp in 1870, he devoted himself more particularly to stellar spectroscopy, and prominently to that branch which had yielded Dr. Huggins such brilliant results.

It must be remembered that at this time the subject was young, and it had been shown by its founder that the utmost accuracy in the construction of the apparatus employed was essential. Instruments had to be invented and their errors determined with the greatest nicety; and Dr. Vogel's appreciation of these difficulties was well manifested in his minute attention to the details of his apparatus.

The spectroscope he employed, was constructed by Schröder, and consisted of five direct vision prisms, with a refracting angle of 90°. The special features of the instrument were—the object glass of the telescope being of the same aperture and focal

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length as the collimator lens, and the size of the latter being adapted to the cone of light coming from the object glass of the large 11½-inch refractor, so that all the rays could be made use of. Great stability was insured by special supports, and the performance of the instrument left nothing to be desired.

The comparison hydrogen-spectrum was so arranged, that the bright lines of the gas spectrum should extend across the whole field of view of the telescope. In this way the bright lines were seen on either side of the band-like stellar-spectrum, and thus any error from the estimation of coincidence of two lines, on one side only, was eliminated.

With this apparatus, Dr. Vogel, in the year 1871, observed and measured the principal lines in the spectra of several stars, reducing them to wave-lengths, and adopting the scale given in Ångström's chart. He measured the displacement of the F hydrogen line in the spectra of *Sirius*, *Procyon*, *Capella*, *Altair*, and *Vega*, and his determination of their motions in the line of sight, published in the *Astronomische Nachrichten*, was strikingly confirmatory of the results previously obtained by Huggins.

Viewing these observations under the light of more recent researches, it must be admitted that the instrumental means employed were hardly adequate for so delicate an inquiry, and the amount of these motions must necessarily be considered only as approximate.

For four years Dr. Vogel pursued his spectroscopic researches at the Bothkamp Observatory, not only in measuring the spectra of stars, and the determination of their motions in the line of sight, but in other directions which will be referred to later on. It may be sufficient to say here, that it was the excellence and success of his work at this observatory, in so many new directions, that led to the founding of the Astrophysical Observatory at Potsdam in the year 1874. Of the extent and importance of the work done at this institution, through the origination, and under the superintendence, of Dr. Vogel, the eight volumes of published results bear ample testimony.

For fifteen or sixteen years, the method of determining the motions of stars in the line of sight had remained undeveloped from the condition in which it left the hands of Huggins, and no progress was made in the accuracy attained by him. But about the year 1887, experiments were made at Potsdam by a photographic application of the method, which showed that a sufficiently great dispersion could be made use of, to readily detect and measure the displacement of the spectral lines produced by the radial motion of the stars.

In his memoir already referred to, published in 1868, Dr. Huggins mentions that the chief difficulties he had to encounter, in spectroscopic observations of the stars, arose from the unsteadiness of the atmosphere. Unless the air is very steady, the lines were seen too fitfully to permit of any certainty in the determination of coincidences of the degree of delicacy required

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in his investigations. He says that he "passed hours in the attempt to determine the position of a single line, and had then not considered that the numerous observations which he had obtained were possessed, even collectively, of sufficient weight to establish with any certainty the coincidence of the line with the one compared with it." One remarkable result of Dr. Vogel's photographic method, was the discovery that the disturbances of the atmosphere exert their influence in a lesser degree on the photograph than on the eye in direct observations. Such unsteadiness in our atmosphere, as would defeat all attempts at accurate eye observation, is of little consequence when the rays are allowed to fall upon the sensitive photographic plate. The continually varying refractions which cause the star image to be at one instant on the slit of the spectroscope, and the next instant off it, appear to be of small moment, for they only affect the time of exposure. The plate faithfully records all the rays that fall upon it, however rapidly these alternate appearances and disappearances recur.

The application of photography to the determination of the motions of stars in the line of sight, in the hands of Dr. Vogel, assisted by Dr. Scheiner, has yielded results which are nothing short of surprising; and the investigation has been conducted with such refined and scrupulous attention to the elimination of errors, as renders it worthy of our highest acknowledgment.

These researches are contained in the seventh volume of the Publications of the Astrophysical Observatory at Potsdam, and the observations were made in the years 1888 to 1890.

In the construction of the apparatus—called the Spectrograph—the following points were taken into consideration:—Great stability for the smallest possible weight; suitable dimensions of prisms, collimator, and camera objectives, in order to preserve sufficient brightness with the greatest possible dispersion; accurate adjustment of the photographic plate in the focal plane of the camera objective; and exact keeping of the star on the slit of the spectrograph. The first two conditions were satisfied by making the frame of cast steel, and by giving it a form which offered the greatest possible resistance to flexure. The detailed construction of the apparatus has already been given in the publications of the Society, and further repetition is hardly necessary. Suffice it to say that the utmost attention was given to secure such stability that very small displacements of the lines in the stellar spectra could be photographed and measured.

The performance of the instrument was tested on the Sun by direct observations, and by photographs; and the accuracy of the measures, as well as the correctness of the adjustment, are well and most satisfactorily indicated by the following observations of the motion of *Venus*:—

		Observed Velocity.	Calculated Velocity.
1889	Jan. 2	−7·8	−7·4 English miles
	Feb. 10	−7·4	−7·8 „

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No better proof than these figures afford, could be given of the refinement which Dr. Vogel has introduced into every part of his work. In particular, he has taken the greatest precaution in respect of the insidious influence of changes of temperature on the apparatus generally, and especially in the comparison of stellar photographs under the microscope with solar ones taken at a different temperature.

He has employed different methods of measurement under the microscope of the displacement of the stellar lines relatively to the artificial ones, according to the type of star and the character of its lines. These are, however, of too technical a nature for detailed description on this occasion, and I must therefore refer to his original memoir, where every part of his investigation is fully described. Mention should, perhaps, be made of his employment of the spectrum of iron for comparison with *Sirius* and some other stars. He was thus able to measure the displacement in as many as eleven different iron lines compared with stellar ones.

The first important result obtained, was the proof of the influence of the Earth's motion on the displacement of the lines, which the earlier direct observations had failed to show with accuracy. As examples, I quote the results for three stars.

	Observed Velocity.	Earth's Velocity.	Velocity of Star reduced to the Sun.	
		α Tauri.		
1888 Oct. 28	+18·1	− 9·5	+27·6	English miles
Nov. 10	+24·9	− 5·9	+30·8	„
Dec. 4	+30·6	+ 1·8	+28·8	„
1890 Jan. 9	+43·7	+12·3	+31·4	„
		α Ophiuchi.		
1888 Sept. 30	+27·6	+14·1	+13·5	„
1889 June 7	+ 9·7	− 1·0	+10·7	„
		α Ursæ Majoris.		
1888 Nov. 7	−17·0	−11·9	− 5·1	„
9	−18·1	−11·9	− 6·2	„
1889 May 4	+ 5·2	+11·8	− 6·6	„
22	+ 3·4	+11·2	− 7·8	„

The consideration of these remarkable results will at once suggest the question: May we not be able, in the future, by the spectroscopic measurement of the radial motions of stars, to determine the earth's velocity in her orbit? In that case, we shall be forced to the astounding conclusion that by observations

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of stars, whose parallactic displacement is absolutely insensible, we are yet able to determine the important unit of measurement in our system—the solar parallax.

The difficulties in the early observations arising from atmospheric tremor, to which I have already referred, disappear in great measure when a much more powerful spectroscope is employed, so that the difference of position between the star line and the comparison line, is much more obvious to the eye. Especially is this the case when the great dispersion of a modern grating is made use of.

Armed with these advantages, Keeler has shown that on *objects which are bright enough*, the eye can well hold its own as compared with the photographic plate. His measures of *Venus* show well what the eye can do.

Venus.

	Observed Motion.	Calculated Motion.
1890 Aug. 16	−7·3	−8·1 miles
22	−8·9	−8·2 „
30	−7·3	−8·3 „
Sept. 3	−8·3	−8·3 „
4	−8·2	−8·3 „

It is especially gratifying to find that, in the case of a star of sufficient brightness, and which possesses a suitable spectrum, the eye observations at the Lick Observatory agree minutely with the results of the measurements of the photographic plates at Potsdam.

Arcturus.

Mean of observations at Potsdam −4·4 ± 0·2

Mt. Hamilton (Keeler).

1890 Apr. 10	−4·6 miles
Aug. 7	−4·0 „
15	−4·2 „
Mean	−4·3

There can now be no longer any hesitation in accepting the motions which Dr. Vogel has given us of his fifty-one stars, as, indeed, very near the truth; and in recognising the immense importance of this method of astronomical observation.

The photographic work at Potsdam has not only given to us the radial motions of fifty-one stars, but from it have resulted two discoveries of very high interest—namely, the compound nature and true cause of the variability of *Algol*; and the duplicity of *Spica*, where, from the inclination of the orbit relatively to the

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line of sight, no variation of its light is produced by its obscure companion.

Indeed, at Harvard, the discovery of two remarkable binary stars had already been made—namely, ζ *Ursæ Majoris*, and β *Aurigæ*, but the Harvard photographs, taken with a slitless form of spectroscope (the prisms being arranged before the object glass of the telescope in the manner first used by Fraunhofer, and later revived by Secchi), do not permit of a direct comparison of the star's spectrum with terrestrial spectra.

In the case of the binary star *Algol*, only one star is bright, and, consequently, there would be no doubling of the lines as shown in the Harvard photographs of β *Aurigæ*. but only a small shift of the lines to and fro in the spectrum, as the bright star moved in its orbit towards or from the Earth, and this would need for its detection the fiducial positions of terrestrial lines for comparison with them.

Twelve photographs of *Algol*, taken by Dr. Vogel in the years 1888 to 1891, when his researches on stellar motion terminated, were measured independently by him and by Dr. Scheiner, and the comparison of their results, when reduced to the Sun, show, what is practically, perfect agreement. From the discussion of the displacement of the lines, our Medallist made the interesting discovery of a motion of approach and recess, corresponding to the known variation of its light of 68·8 hours.

Thus, the explanation suggested by Goodricke, a century ago, that the variability of *Algol* was due to the periodic transit of an opaque body revolving round the star, was proved to be the true one.

The Potsdam photographs show that before minimum the bright star is receding at the rate of 24·4 English miles a second, while after the minimum has been passed the star approaches us with the velocity of 28·6 miles a second. From these velocities it follows that the system of *Algol* is approaching our system at the rate of 2·3 miles a second, and that the visible star has a velocity in its orbit of 26·3 miles. Assuming that both the bright and dark components have the same density, so that their masses are directly as their volumes, Dr. Vogel gives the following particulars of the system :—

	English Miles.
Diameter of *Algol*	1,061,000
Diameter of dark companion	830,300
Distance of centre	3,230,000
Motion of *Algol* in its orbit	26·3 miles per second
Motion of companion	55·4 „ „
Mass of *Algol*	$\frac{4}{9}$ of Sun's mass
Mass of companion	$\frac{2}{9}$ „

In the case of *Spica* the method followed was to photo-

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graph on the same plate the spectrum of the star and that of terrestrial hydrogen, and the displacement of the star lines was measured with the microscope. These measurements were made with considerable difficulty, owing to the fact that the hydrogen lines in the spectrum of this star are broad and ill-defined; and in this and similar cases a special method had in consequence to be adopted. The result of the measurement of twenty-seven photographs, was to show that the star lines are displaced alternately towards the red and violet ends of the spectrum, in a complete period of about four days, the maximum displacement towards the violet, indicating a motion towards the Sun of 65·9 English miles, and that towards the red, a receding motion of 47·5 miles.

These observations are completely explained on the supposition that *Spica* is a binary star, one component of which is too faint to be detected by any means at present at our disposal. The orbital velocity of the bright star is 56·7 miles a second, and the system is approaching the Sun at the rate of 9·2 miles a second. The following are the elements:—

a Virginis.

$$\text{Velocity in line of sight} - \text{velocity of system} = 56{\cdot}7 \sin\left(\frac{t-t_0}{p}\right) 360^\circ \text{ in miles}$$

Velocity of system = − 9·2 miles

Period p = 4·0134 days

Epoch t_0 = 1890 May 4, $10^{\text{h}}{\cdot}50$ Potsdam m. t.

Assuming a circular orbit, and that the components have equal mass, then the mass of the system is 2·6 times that of the sun, and the components are separated by about 6¼ millions of miles. Taking the most probable value for the star's parallax, the angular separation of the stars would be $0''{\cdot}014$, a quantity far too small to be detected by the most powerful telescopes.

It should be mentioned that Dr. Vogel conceives that some traces of the spectrum of the faint companion can be made out in the photographs, in the unsymmetrical appearance of the hydrogen lines at the time of maximum motion, and a greater sharpness of other lines at the time of minimum motion.

The new light thrown upon the constitution of the heavens by these remarkable discoveries excites our imagination in the highest degree, and may easily lead us into the wide fields of conjecture and speculation; for there can be little doubt that many such systems exist, which future observations will make known to us. The spectacle of two suns, each as large as our own, revolving round each other in a few days, is one that has been revealed to us by indirect means it is true; but it is also true that the evidence depends upon laws and principles so well investigated, and so well understood, that what might

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otherwise bear the aspect of romance, must be accepted as a logical, scientific, and indisputable deduction.

Before passing from this subject, I should not omit to state that shortly after Dr. Huggins's original observations, the new method of observation of radial motions was taken up systematically at the Royal Observatory, Greenwich, and at the Temple Observatory, Rugby. From 1874 until 1890 the work was pursued assiduously at Greenwich, and every observation made has been communicated to the Society and published in the *Monthly Notices.*

To secure accurate data by which posterity may be able to recognise the changes that are possibly continually, and progressively, taking place in the heavens, is an important duty that devolves upon us in return for the enormous advantages and facilities which modern scientific research has placed at our disposal. It was the recognition of this obligation that brought about the recent international organisation for the construction of a photographic chart of the heavens, and it was the same consideration in the mind of our Medallist that led him to commence the laborious work of a Spectroscopic *Durchmusterung.* To this intent, Dr. Vogel, assisted by Dr. Müller, in the years 1880 to 1882, observed the spectra of all stars to the 7·5 magnitude situated in the zone between the parallels of 1° south and 20° north declination.

The results were published in the third volume of the publications of the Potsdam Observatory, and form a catalogue of the spectra of 4,051 stars.

It is very gratifying to note that this important undertaking has now been completed between the Pole and 15° south declination: the observations between the Equator and −15° having been made by Dr. Konkoly at the O'Gyalla Observatory, and those from 20° north declination to the Pole by Dr. Dunér.

The spectra of the stars examined by Dr. Vogel are classified according to the three types of the system adopted by him. It will be remembered that from his voluminous researches he had been led to a classification of stellar spectra differing somewhat from that adopted by Secchi, inasmuch as he combines the third and fourth types of the latter physicist, into one division. Accepting the hypothesis of Zöllner, that yellow and red stars are simply white stars in various stages of cooling, he considered the white stars of Class I. as the hottest and youngest members of the sidereal family; those of the Solar type, as having wasted much of their store of radiation; while the red stars with banded spectra are viewed as "effete suns hastening rapidly down the road to final extinction." But whatever views may come to be adopted ultimately of the relation to each other of the different stellar types, Dr. Vogel's system of arrangement has been of considerable assistance in the record and comparison of stellar spectra.

In solar physics Dr. Vogel's researches place him in the

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forefront of those who have laboured at this branch of astronomy, created by the invention of the spectroscope. While at Bothkamp numerous observations were made, and the discoveries that resulted are of much interest.

It had occurred to both Secchi and Zöllner, that from the unequal displacement of the F or the C line, when observed at the two opposite points of the Sun's equator, the velocity of solar rotation might be ascertained. If a spectrum line be observed on the eastern limb of the Sun, which is approaching the observer, it will, in comparison with its position in the centre of the disc, appear to be displaced towards the violet, whereas observations of that line on the western limb, which is receding from us, would show a displacement in the opposite direction. For such a delicate investigation, Zöllner had invented a Reversion-Spectroscope, by which instrument two spectra could be brought into juxtaposition, but with the lines in reverse order, so that the measurable effect of any displacement of the lines would be doubled, as the deviation in each spectrum is in an opposite direction.

With such an instrument Dr. Vogel, in 1871, at Bothkamp, while observing the Sun's limb, was able to detect an undoubted displacement of the F line, the cause of which was traceable to the Sun's rotation, and thus for the first time the *fact* of rotation was proved by the spectroscope.

This method of determining the rotation of the Sun, has recently been very successfully developed by Dr. Dunér, who has succeeded, not only in measuring the displacement of the lines on the solar equator, and so measuring the velocity of equatorial rotation, but has also been able to measure the diminution of the angular velocity of rotation in higher heliocentric latitudes, which had been discovered from observations of sunspots.

No better test, if such were needed, could be devised of the soundness of the conclusions as to the cause of such displacements in the observations of stellar spectra.

In the year 1877 the intensity of solar radiation occupied the attention of Dr. Vogel. It had been earlier remarked by Secchi in his investigation of the absorption of the solar atmosphere on the luminous rays, that the light from the limb of the Sun is not white, but reddish-brown. This indication of selective absorption, showed the importance of investigating by some photometric method, the loss suffered by rays of different refrangibilities.

Our Medallist was thus led to design a new spectrum-photometer, which was constructed on the principle of the polarising photometer invented by Glans. The results he obtained with this instrument are of the greatest interest.

In his skilful hands, he was able to compare with great accuracy and directly, the brightness of the rays of different refrangibilities proceeding from different parts of the Sun's disc.

The results are contained in the following table. In the first

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column is given the distance of the point from the Sun's centre in percentage of the Sun's radius, and the other columns give the ratio between the light of the given colour at the centre and at the given point.

D	Violet $\left.\begin{matrix}412\\405\end{matrix}\right\}\mu\mu$	Dark Blue $\left.\begin{matrix}446\\440\end{matrix}\right\}\mu\mu$	Blue $\left.\begin{matrix}473\\467\end{matrix}\right\}\mu\mu$	Green $\left.\begin{matrix}515\\510\end{matrix}\right\}\mu\mu$	Yellow $\left.\begin{matrix}585\\573\end{matrix}\right\}\mu\mu$	Red $\left.\begin{matrix}666\\658\end{matrix}\right\}\mu\mu$
0	100·0	100·0	100·0	100·0	100·0	100·0
5	99·9	99·9	99·9	99·9	99·9	100·0
10	99·6	99·7	99·7	99·7	99·8	99·9
15	99·2	99·3	99·3	99·3	99·5	99·7
20	98·5	98·7	98·8	98·7	99·2	99·5
25	97·5	97·8	98·1	97·9	98·8	99·3
30	96·3	96·8	97·2	96·9	98·2	98·9
35	95·0	95·6	96·1	95·7	97·5	98·5
40	93·4	94·1	94·7	94·3	96·7	98·0
45	91·2	92·2	93·1	92·6	95·7	97·4
50	88·7	90·2	91·3	90·7	94·5	96·7
55	85·7	87·8	89·3	88·6	92·9	95·9
60	82·4	84·9	87·0	86·2	90·9	94·8
65	78·7	81·7	84·2	83·4	88·0	93·2
70	74·4	77·8	80·8	80·0	84·5	91·0
75	69·4	73·0	76·7	75·9	80·1	88·1
80	63·7	67·0	71·7	70·9	74·6	84·3
85	56·7	59·6	65·5	64·7	67·7	79·0
90	47·7	50·2	57·6	56·6	59·0	71·0
95	34·7	35·0	45·6	44·0	46·0	58·0
100	13·0	14·0	16·0	16·0	25·0	30·0

The consideration of these figures shows that of the violet rays, only 13 per cent. penetrate the solar atmosphere at the limb, of the indigo 14 per cent., of the blue and green 16 per cent., 25 per cent. of the yellow, and 30 per cent. of the red.

From the complete analysis of the Sun's light from the centre to the edge of the disc afforded by the above table, we see that the colour at the limb must be different from that at the centre of the disc, since more of the violet rays are absorbed than the red. The observations show, also, a much more rapid degradation of the light towards the limb, and so indicate a thin and dense atmosphere. In discussing his results, according to the fundamental law of radiation that an incandescent sphere appears sensibly of equal brightness all over, the foreshortening of each area inclined to the line of sight compensating for its diminished radiation, Dr. Vogel finds that if the absorbing

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envelope of the Sun were removed, the brightness of the red rays of the visible spectrum would be increased about 1·49 times, and the violet rays 3·01 times.

The rapid development of spectroscopy soon rendered necessary a reconstruction and completion of Ångström's Map of the Solar Spectrum. This work, which was first undertaken by Mr. Lockyer, was subsequently taken up by Dr. Vogel at Potsdam, who made a long series of accurate measures, and took a vast number of photographs between F and H—from 489 to 389 millionths of a millimetre of wave-length; and the result is a map of this portion of the solar spectrum no less than 17 feet long. The less refrangible end was later completed by Dr. Müller. Under Dr. Vogel's superintendence, Drs. Müller and Kempf made original determinations of the wave-lengths of 300 lines, by the aid of which the wave-lengths of all the lines in the Potsdam map were newly fixed with an accuracy considerably greater than that of the scale of Ångström, then almost exclusively in use.

Not the least valuable of the spectroscopic observations, pursued with the same unwearying assiduity by our Medallist, are those he made on the spectra of the planets.

In examining the spectra of bodies like the planets, which shine solely by the reflected light of the Sun, the only differences from the solar spectrum we should expect to find, would be those due to the absorbing influences of their atmospheres. Such absorption bands had been measured in the principal planets by Huggins and Secchi, but at Bothkamp Dr. Vogel succeeded in making the most complete measurements we possess of the lines in the spectra of all the planets, and determined the refrangibility of the principal absorption bands. The interesting question of the causes of some of these bands is at present undecided, and though the observations indicate the existence of aqueous vapour in the atmospheres of some of the planets, yet bands were observed by him in the spectra of *Jupiter*, *Saturn*, and *Uranus*, which suggest a difference in the constitution of the gaseous envelopes surrounding those planets compared with that of our terrestrial atmosphere. For these important researches Dr. Vogel was awarded a prize by the Copenhagen Academy.

Besides observing the spectra of Nebulæ, Clusters, and Comets, he, in 1871, instituted measures of the bright lines visible in the spectrum of the Aurora, and determined with great exactness the wave-lengths of about seven lines. Hitherto the identification of the Auroral spectrum has not been satisfactorily established, the principal line in the green being quite unknown. Dr. Vogel, however, was strongly inclined to the opinion that the spectrum is merely a modification of that of air, but the origin of these lines is still an open question.

The spectrum of Lightning also engaged his attention, and, notwithstanding the difficulty of such observations, the positions of the brightest lines were accurately measured by him and Dr.

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Lohse with the stellar spectroscope of the Bothkamp Observatory. Suffice it to say that his observations appear to have been fully confirmed by those made more recently.

In determining this award the Council desired to include other astronomical researches of Dr. Vogel, apart from those depending on the spectroscope, and it is my duty here to allude to them, though in the briefest terms.

While an assistant at the Leipzig Observatory he made two important series of observations on nebulæ and clusters, in which the positions of about 240 of these objects were determined with an exactness sufficient to make them of great value in any discussion of nebular parallax. In this respect these observations of Dr. Vogel have probably not been surpassed. At this period, also, he prepared a memoir giving the results of his micrometric measures and photometric determination of 176 stars, ranging from 6·5 to 13 magnitude, in one portion of the great cluster in *Perseus*; the investigation of the other portion of this double cluster having been previously made by Krüger at Helsingfors. In this work, the care exercised in the determination of the zero of position, and in the investigation of the micrometer, are characteristic of the author; and the accuracy of the results is satisfactorily shown by the very small probable errors of the positions of the brighter stars, and by the indication in one of them, of a possible parallax of 0″·3. In undertaking these researches his object was to fix relative positions, so that any future change might be detected. Probably, however, in the future we shall rely more upon the photographic astronomer to discover and inform us of changes in the heavens, than upon such laborious investigations as those made with the micrometer.

Finally, I would desire to refer to our Medallist's observations of *Jupiter's* satellites.

The determination of the mass of *Jupiter* has been repeatedly undertaken, and the values we possess of this important constant, have been derived either from heliometer measures, and transit observations of the satellites, or from planetary perturbations. In order to furnish additional data for such an inquiry, Dr. Vogel, while at Leipzig, made a long series of transit observations of the 3rd and 4th Satellites. These observations have been used by Dr. Kempf in his investigation of the mass of *Jupiter* contained in the third volume of the Potsdam publications, in which he combines the most reliable researches that had been made on the subject. His definitive result of $\frac{1}{1047·700}$ differs insensibly from the value of $\frac{1}{1047·767}$ derived from Dr. Vogel's observations alone. This satisfactory agreement indicates clearly the excellence of his Leipzig observations, which were made in the years 1868 to 1870.

In the brief and very imperfect review of Dr. Vogel's labours which I have brought before you, I can scarcely hope to have

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succeeded in adequately explaining the admirable services which he has rendered to Astronomy. I have dwelt upon the refined character of his observations, and the extreme care with which all his researches have been conducted. It is a record of unwearying perseverance to accomplish great work; moreover, it is the chronicle of a masterly attainment of success.

Such achievements as those gained by the spectroscope at Potsdam, reveal to us what Lubbock happily terms "the exquisite possibilities of science." Not only is Astronomy enriched by a series of investigations of the greatest value, but a distinct, and, indeed, marvellous advance is made in our knowledge and conception of the stellar universe.

Notwithstanding many deficiencies, I trust I have been able to justify the action of the Council to you, in their desire to honour, in the highest degree, one who has laboured so earnestly, so devotedly, and with such distinguished success for our science.

The President then, delivering the Medal to the Foreign Secretary, addressed him in the following terms:—

Dr. Huggins, It is with peculiar interest I place in your hands this medal, and request you to transmit it to our distinguished Associate Dr. Vogel, who, we much regret, is unable to be present to-day; for I can well understand the satisfaction it must be to you, who occupy so classic a position in Spectroscopic Astronomy, to be the medium of conveying this mark of our highest appreciation to one who has developed with such signal success the branch of Observational Astronomy which you originated in 1868. In congratulating him upon the splendid results he has obtained, we would, at the same time, express the full satisfaction with which we have watched the progress of the important institution he directs, and our obligations for its great services to Astrophysics. Assure him of our continued interest in his valuable researches, and that we trust the knowledge of the high estimation in which they are held, may stimulate him to even greater and more noble achievements, which, with the blessing of health and strength, we confidently expect from him.